THE PAST CENTURY.

Its Progress in Great Subjects.

A SET OF REMARKABLE ARTICLES

Eighth Paper of the Series, by Prof. Elihu Thomson.

"ELECTRICITY."

The great importance which electricity has attained in many departments of human activity is so constantly evident that we have difficulty in realizing how short is the time which has been occupied in its development. The latter half of the nineteenth century must ever remain memorable, not only for the great advances in nearly all the useful arts, but for the peculiarly rapid electric progress, and the profound effect which it has had upon the lives and business of the people. In the preceding century we find no evidences of the application of electricity to any useful purpose. Few of the more important principles of the science were then known. Franklin's invention of the lightning rod was not intended to utilize electric force, but to guard life and property from the perils of the thunderstorm. The numerous instructive experiments in frictional electricity, the first known form of electric manifestation except lightning, made clear certain principles, such as conduction and insulation, and served to distinguish the two opposite electric conditions known as positive and negative. Franklin's kite experiment confirmed the long suspected identity of lightning and electric sparks. It was not, however, until the discovery by Alexander Volta in 1799 of his pile, or battery, that electricity could take its place as an agent of practical value. Volta, when he made this great discovery, was following the work of Galvani, begun in 1786. But Galvani in his experiments mistook the effect for the cause and so missed making the unique demonstration that two different metals immersed in a solution could set up an electric current. Volta, a professor in the university of Pavia and a foreign member of the Royal Society of England, communicated his discovery to the president of the society in March, 1800, and brought to the notice of the world the first means for obtaining a steady flow of electricity. Before this event electric energy had been known to the experimenter in pretty effects of attraction and repulsion of light objects, in fitful flashes of insignificant power, or as it appeared in nature, in the fearful bursts of energy during a thunderstorm, uncontrolled and erratic. The analogous and closely related phenomena of magnetism had already found an important application in the navigator's compass.

The simplest facts of electro-magnetism, upon which much of the later electrical developments depend, remained entirely unknown until near the close of the first quarter of the nineteenth century. Magnetism itself, as exemplified in loadstone or in magnetized iron or steel, had long before been consistently studied by Dr. Gilbert of Colchester, England, and in 1600 his great work, "De Magnete," was published. It is a first example, and an excellent one, too, of the application of the inductive method, so fruitful in after years. The restraints which a superstitious age had imposed upon nature study were gradually removed, and at the beginning of the century just past occasional decided encouragement began to be given to physical research. It was this condition which put into the hands of Humphrey Davy of the Royal Institution in London, at the opening of the century, a voltaic battery of some 250 pairs of plates. With this a remarkably fruitful era of electric discovery began. In 1802 Davy first showed the electric arc or "arch" on a small scale between pieces of carbon. He also laid the foundation for future electro-chemical work by decomposing by the battery current potash and soda, and thus isolating the alkali metals potassium and sodium for the first time. This was in 1807, and the result was not only greatly to advance the youthful science of chemistry but to attract the attention of the world to a new power in the hands of the scientific worker, the electric current. A fund was soon subscribed by "a few zealous cultivators and patrons of science" interested in the discovery of Davy, and he had at his service in 1801 no less than 2,000 cells of voltaic battery. With the intense currents obtained from it he again demonstrated the wonderful and brilliant phenomenon of the electric arc, by closing the circuit of the battery through terminals of hardwood charcoal and then separating them for a short distance. A magnificent arch of flame was maintained between the separated ends, and the light from the charcoal pieces was of dazzling splendor. Thus was born into the world the electric arc light, of which there are now hundreds of thousands burning nightly in our country alone.

Davy probably never imagined that his brilliant experiment would soon play so important a part in the lighting of the world. He may never have regarded it as of any practical value. In fact, many years elapsed before any further attempt was made to utilize the light of the electric arc. The reason for this is not difficult to discover. The batteries in existence were crude and gave only their full power for a very short time after the circuit was closed. They were subject to the very serious defect of rapid polarization, whereby the activity was at once reduced. A long period elapsed before this defect was removed. Davy in his experiments had also noted the very intense heat of the electric arc, and found that but few substances escaped fusion or volatilization when placed in the heated stream between the carbon electrodes. Here again he was pioneer in every important and quite recent electric work, employing the electric furnace, which has already given rise to several new and valuable industries.

The conduction of electricity along wires naturally led to efforts to employ it in signalling. As early as 1774 attempts were made by Le Sage of Geneva to apply frictional electricity to telegraphy. His work was followed before the close of the century by other similar proposals. Volta's discovery soon gave a renewed impetus to these efforts. It was easy enough to stop and start a current in a line of wire connecting two points, but something more than that was requisite. A good receiver, or means for recognizing the presence or absence of current in the wire or circuit, did not exist. The art had to wait for the discovery of the effects of electric currents upon magnets and the production of magnetism by such currents. Curiously, even in 1802 the fact that a wire conveying a current would deflect a compass needle was observed by Romagnosi of Trente, but it was afterward forgotten, and not until 1819 was any real advance made.

It was then that Oersted of Copenhagen showed that a magnet tends to set itself at right angles to the wire conveying a current and that the direction of turning depends on the direction of the current. The study of the magnetic effects of electric currents by Arago, Ampère, and the production of the electro-magnet by Sturgeon, together with the very valuable work of Henry and others, made possible the completion of the electric telegraph. This was done by Morse and Vail in America, and almost simultaneously by workers abroad, but before Morse had entered the field Prof. Joseph Henry had exemplified by experiments the working of electric signalling by electro magnets over a short line. It was Henry, in fact, who first made a practically useful electro-magnet of soft iron. The history of the electric telegraph teaches us that to no single individual is the invention due. The Morse system had been demonstrated in 1837, but not until 1844 was the first telegraph line built. It connected Baltimore and Washington and the funds for defraying its cost were obtained from Congress only after a severe struggle. This can easily be understood, for electricity had not up to that time ever been shown to have any practical usefulness. The success of the Morse telegraph was soon followed by the establishment of telegraph lines as a means of communication between all the large cities and populous districts. Scarcely ten years elapsed before the possibility of a transatlantic telegraph was mooted. The cable laid in 1858 was a failure. A few words passed and then the cable broke down completely. This was found to be due to defects in construction. A renewed effort to lay a cable was made in 1866, but disappointment again followed; the cable broke in mid-ocean and the work again ceased. The great task was successfully accomplished in the following year, and the pluck and pertinacity of those who were staking their capital, if not their reputations for business sagacity, were amply rewarded. Even the lost cable of 1866 was found, spliced to a new cable, and completed soon after as a second working line. The delicate instruments for the working of these long cables were due to the genius of Sir William Thomson, now Lord Kelvin, whose other instruments for electrical measurement have for years been a great factor in securing precision both in scientific and practical testing. The number of cables joining the Eastern and Western hemispheres has been increased from time to time and the opening of a new cable is now an ordinary occurrence calling for little or no especial note.

The introduction of the electric telegraph was followed by the invention of various signalling systems, the most important being the fire-alarm telegraph as suggested by Channing and worked out by Farmer. We now, also, have automatic clock systems in which a master clock controls or gives movement to the hands of distant clock dials by electric currents sent out over the connecting or circuit wires. Automatic electric signals are made when fire breaks out in a building, and alarms are similarly rung when a burglar breaks in. Not only do we have telegraphs which print words and characters, as in the stock "ticker," but in the form known as the teleautograph, invented by Dr. Elisha Gray, the sender writes his message, which writing is at the same time being reproduced at the receiving end of the line. Even pictures or drawings are "wired" by special instruments. The desirability of making one wire connecting two points do a large amount of work, and thus avoiding the addition of new lines, has led to two remarkable developments of telegraphy. In the duplex, quadruplex and multiplex systems, several messages may at the same time be traversing a single wire line without interference one with the other. In the rapid automatic systems the working capacity of the line is increased by special automatic transmitting machines and rapid recorders, and the electric impulses in the line itself follow each other with great speed.

Improvement in this field has by no means ceased, and new systems for rapid transmission are yet being worked out. The object is to enlarge the carrying capacity of existing lines connecting large centres of population. The names of Wheatstone, Stearns, Edison and Delaney, are prominent in connection with this work. For use in telegraphy the originally crude forms of voltaic battery, such as Davy used, were replaced by the more perfect types, such as the constant battery of Daniell, the nitric acid battery of Grove, dating from 1836, and the carbon battery of Bunsen, first brought out in 1842. Such was the power of the Grove and Bunsen batteries that attention was again called to the electric arc and to the possibility of its use for electric illumination. Accordingly we find that suggestions were soon made for electric arc lamps to be operated by these more powerful and constant sources of electric current. The first example of a working type of an arc lamp was that brought to notice by W. E. Staite in 1847, and his description of the lamp and the conditions under which it could be worked is a remarkably exact and full statement considering the time of its appearance. Staite even anticipated the most recent phase of development in arc lighting, namely, the inclosure of the light in a partially air-tight globe to prevent too rapid waste of the carbons by combustion in the air. In a public address at Newcastle-on-Tyne in 1847, he advocated the use of the arc, so inclosed, in mines as obviating the danger of fire. But it was a long time before the electric arc acquired any importance as a practical illuminant. There was, indeed, no hope of its success so long as the current had to be obtained from batteries consuming chemicals and zinc. The expense was too great, and the batteries soon became exhausted. In spite of this fact occasional exhibitions of arc lighting were made, notably in 1856, by Lacassagne and Thiers, in the streets of Paris.

For this service they had invented an arc lamp involving what is known as the differential principle, afterward applied so extensively to arc lamps. The length of the arc or the distance between the carbons of the lamp was controlled with great nicety and the light thus rendered very steady. Even as late as 1875 batteries were occasionally used to work single electric arc lamps for public exhibitions, or for demonstration purposes in the scientific departments of schools. The discovery of the means of efficiently generating electricity from mechanical power constitutes, however, the key note of all the wonderful electrical work of the closing years of the nineteenth century. It made electrical energy available at low cost. Michael Faraday, a most worthy successor of Davy at the Royal Institution, in studying the relations between electric currents and magnets, made the exceedingly important observation that a wire, if moved in the field of a magnet, would yield a current of electricity. Simple as the discovery was, its effect has been stupendous. Following his science for its own sake, he unwittingly opened up possibilities of the greatest practical moment. The fundamental principle of the future dynamo electric machine was discovered by him. This was in 1831. Faraday's investigations were so complete and his deductions so masterly, that little was left to be done by others. Electro-magnetism was supplemented by magneto-electricity. Both the electric motor and the dynamo generator were now potentially present with us. Faraday contented himself with pointing the way, leaving the technical engineer to follow. In one of Faraday's experiments a copper disk mounted on an axis passing through its centre was revolved between the poles of a large steel magnet. A wire touched the periphery of the disk at a selected position with respect to the magnet and another was in connection with the axis. These wires were united through a galvanometer or instrument for detecting electric current. A current was noted as present in the circuit so long as the disk was turned. Here then was the embryo dynamo. The century closes with single dynamo machines of over 5,000 horse power capacity, and with single power stations in which the total electric generation by such machines is 75,000 to 100,000 horse power. So perfect is the modern dynamo that out of 1,000 horse power expended in driving it, 950 or more may be delivered to the electric line as electric energy. The electric motor, now so common, is a machine like the dynamo, in which the principle of action is simply reversed; electric energy delivered from the lines becomes again mechanical motion or power.

Soon after Faraday's discoveries in magneto-electricity, attempts were made to construct generators of electricity from power. But the machines were small, crude and imperfect and the results necessarily meagre.

Pixii, in Paris, one year after Faraday's discovery was announced, made a machine which embodied in its construction a simple commutator for giving the currents a single direction of flow. This is the prototype of the commutators now found on what are called continuous current dynamos. After Pixii followed Saxton, Clarke, Wheatstone and Cooke, Stohrer and others, but not until 1854 was any very notable improvement made or suggested. In that year Soren Hjorth of Copenhagen described in a patent specification the principle of causing the electric currents generated to traverse coils of wire so disposed as to reenforce the magnetic field of the machine itself. A year subsequently the same idea was again more clearly set out by Hjorth. This is the principle of the modern self-exciting dynamo, the field magnets of which, very weak at the start, are built up or strengthened by the currents from the armature or revolving part of the machine in which power is consumed to produce electricity.

In 1856 Dr. Werner Siemens of Berlin, well known as a great pioneer in the electric arts, brought out the Siemens armature, an innovation more valuable than any other made up to that time. This was subsequently used in the powerful machines of Wilde and Ladd. It still survives in magneto call-bell apparatus for such work as telephone signalling, in exploders for mines and blasting, and in the simpler types of electroplating dynamos.

The decade between 1860 and 1870 opened a new era in the construction and working of dynamo machines and motors. It is notable for two advances of very great value and importance. Dr. Paccinotti of Florence, in 1860, described a machine by which true continuous currents resembling battery currents could be obtained. Up to that time machines gave either rapidly alternating or fluctuating currents, not steady currents in one direction. The Paccinotti construction, in modified forms, is now almost universally employed in dynamo machines, and even where the form is now quite different the Paccinotti type has been at least the forerunner and has undergone modifications to suit special ends in view. Briefly, Paccinotti made his armature of a ring of iron with iron projections, between which the coils of insulated wire are wound. Although full descriptions of Paccinotti's ring armature and commutator were given out in 1864, his work attracted but little attention until Gramme, in Paris, about 1870, brought out the relatively perfect Gramme machine. In the meantime the other great development of the decade took place.

Although Hjorth had, as stated before, put forward the idea that a dynamo generator might itself furnish currents for magnetizing its own magnets, this valuable suggestion was not apparently worked out until 1866, when a machine was constructed for Sir Charles Wheatstone. This appears to have been the first self-exciting machine in existence. Wheatstone read a paper before the Royal Society in February, 1867, "On the Augmentation of the Power of a Magnet by the Reaction Thereon of Currents Induced by the Magnet Itself." This action later became known as the reaction principle in dynamo machines.

As often happens, the idea occurred to other workers in science almost simultaneously, and Dr. Werner Siemens also read a paper in Berlin about a month earlier than that of Wheatstone, clearly describing the reaction principle. Furthermore, a patent specification had been filed in the British Patent Office by S. A. Varley, Dec. 24, 1866, clearly showing the same principle of action, and he was, therefore, the first to put the matter on record. The time was ripe for the appearance of machines closely resembling the types now in such extended use. Gramme, in 1870, adopting a modified form of the Paccinotti ring and commutator, and employing the reaction principle, first succeeded in producing a highly efficient, compact and durable continuous-current dynamo. The Gramme machine was immediately recognized as a great technical triumph. It was in a sense the culmination of many years of development, beginning with the early attempts immediately following Faraday's discovery already referred to. Gramme constructed his revolving armature of a soft iron wire ring, upon which ring a series of small coils of insulated wire were wound in successive radial planes. These coils were all connected into a continuous wire and from the junctions of the coils one with another connections were taken to a range of copper bars insulated from each other, constituting the commutator. In 1873 Von Hefner Alteneck in Berlin, modified the ring winding of Gramme and produced the "drum winding," which avoided the necessity for threading wire through the centre of the iron ring, as in the Gramme construction. The several coils of the drum were still connected, as in Gramme's machine, to the successive strips of the commutator.

In modern dynamos and motors the armature, usually constructed of sheet iron punchings, is a ring with projections, as in Paccinotti's machine, and the coils of wire are in most cases wound separately and then placed in the spaces between the projections, constituting in fact a form of drum winding. In the early 70s a few Gramme ring and Siemens drum machines had been applied to the running of arc lights, one machine for each light. There were also some Gramme machines in use for electroplating.

In all dynamos in practical use the currents which are generated are alternating currents, as they are called. Such currents are characterized by rapid changes of direction or reversals. These occur many times per second, and when such currents are to be made into continuous currents flowing in one direction the machine is provided with a commutator for connecting the coils to the circuit, so that the current will always flow in it in the same direction. Great numbers of dynamos, however, are used without commutators for changing the direction of their currents. In such machines the circuit receives, instead of continuous currents, waves of current or alternating currents. As with sound, the waves have a pitch, i. e., they follow each other at a certain number of times per second. In usual practice there will be from 25 waves, which would be a low period, up to 150 or more per second, but machines can be constructed to produce alternating currents of many thousand waves or cycles (as they are termed) per second for special uses. When an alternating current flows from a line there are times when the current is changing from one direction to the other and when there is actually no current, and these are called the zeros, or dead points of the current. Much of the machinery developed in later years has been of the alternating current type, generators, motors, &c., utilizing these rapidly reversing currents.

At the Centennial Exhibition, held at Philadelphia in 1876, but two exhibits of electric lighting apparatus were to be found. Of these one was the Gramme and the other the Wallace-Farmer exhibit. The Wallace-Farmer dynamo machine is a type now obsolete. It was not a good design, but the Wallace exhibit contained other examples reflecting great credit upon this American pioneer in dynamo work. Some of these machines were very similar in construction to later forms which went into very extensive use. The large searchlights occasionally used in night illumination during the exhibition were operated by the current from Wallace-Farmer machines. The Gramme exhibit was a remarkable exhibit for its time. Though not extensive it was most instructive. There were found in it a dynamo running an arc lamp, a large machine for electrolytic work such as electroplating and electrotyping, and, most novel and interesting of all, one Gramme machine driven by power was connected to another by a pair of wires and the second ran as a motor. This in turn drove a centrifugal pump and raised water which flowed in a small fall or cataract. A year or two previously the Gramme machine had been accidentally found to be as excellent an electric motor as it was a generating dynamo. The crude motors of Jacobi, Froment, Davenport, Page, Vergnes, Gaume and many others were thus rendered obsolete at a stroke. The first public demonstration of the working of one Gramme machine by another was made by Fontaine at the Vienna Exhibition of 1873.

Here, then, was a foreshadowing of the great electric power transmission plants of to-day; the suggestion of the electric station furnishing power as well as light, and to a less degree the promise of future railways using electric power. Replace the centrifugal pump of this modest exhibit by a turbine wheel, reverse the flow of water so as to cause it to drive the electric motor so that the machine becomes a dynamo, and in like manner make of the dynamo a motor, and we exemplify in a simple way recent great enterprises using water power for the generation of current to be transmitted over lines to distant electric motors or lights.

The Centennial Exhibition also marks the beginning, the very birth, it may be said, of an electric invention destined to become, before the close of the century, a most potent factor in human affairs. The speaking telephone of Alexander Graham Bell was there exhibited for the first time to the savants, among whom was the distinguished electrician and scientist, Sir William Thomson. For the first time in the history of the world a structure of copper wire and iron spoke to a listening ear. Nay, more, it both listened to the voice of the speaker and repeated the voice at a far distant point. The instruments were, moreover, the acme of simplicity. Within a year many a boy had constructed a pair of telephones at an expenditure for material of only a few pennies. In its first form the transmitting telephone was the counterpart of the receiver, and they were reversible in function. The transmitter was in reality a minute dynamo driven by the aerial voice waves; the receiver, a vibratory motor worked by the vibratory currents from the transmitter and reproducing the aerial motions. This arrangement, most beautiful in theory, was only suited for use on short lines, and was soon afterward replaced by various forms of carbon microphone transmitter, to the production of which many inventors had turned their attention, notably Edison, Hughes, Blake and Hunnings. In modern transmitters the voice wave does not furnish the power to generate the telephone current, but only controls the flow of an already existing current from a battery. In this way the effects obtainable may be made sufficiently powerful for transmission to listeners 1,500 miles away.

There is no need to dwell here upon the enormous saving of time secured by the telephone and the profound effect its introduction has had upon business and social life. The situation is too palpable. Nevertheless, few users of this wonderful invention realize how much thought and skill have been employed in working out the details of exchange switchboards, of signalling devices, of underground cables and overhead wires, and of the speaking instruments themselves. Few of those who talk between Boston and Chicago know that in doing so they have for the exclusive use of their voices a total of over 1,000,000 pounds of copper wire in the single line. There probably exist now in the United States alone between 75,000 and 100,000 miles of hard drawn copper wire for long-distance telephone service, and over 150,000 miles of wire in underground conduits. There are upward of three-quarters of a million telephones in the United States, and, including both overhead and underground lines, a total of more than half a million miles of wire. Approximately, one thousand million conversations are annually conveyed.

The possibility of sub-oceanic telephoning is frequently discussed, but the problem thus far is not solved. It involves grave difficulties and we may hope that its solution is to be one of the advances which will mark the coming century's progress.

The advent of the telephone in 1876 seemed to stimulate invention in the electric field to a remarkable degree. Its immediate commercial success probably acted also to inspire confidence in other proposed electric enterprises. Greater attention than ever before began to be given to the problem of electric lighting. An electric arc lamp, probably the only one in regular use, had been installed at Dungeness lighthouse in 1862, after a long set of trials and tests. It was fed by a Holmes magneto-electric machine of the old type, very large and cumbrous for the work. Numerous changes and improvements had before 1878 been made in arc lamps by Serrin, Dubosq and many others, but the display of electric light during the Paris Exposition of 1878 was the first memorable use of the electric light on a large scale. The splendid illumination of the Avenue de l'Opéra was a grand object lesson. The source of light was the "electric candle" of Paul Jablochkoff, a Russian engineer. It was a strikingly original and simple arc lamp. Instead of placing the two carbons point to point, as had been done in nearly all previous lamps, he placed them side by side with a strip of baked kaolin between them. The candle so formed was supported in a suitable holder whereby at the lower end the two parallel carbons were connected with the circuit terminals. By a suitable device the arc was started at the top and burned down. The electric candle seemed to solve the problem of allowing complicated mechanism for feeding the carbons to be discarded; but it survived only a short time. Owing to unforeseen difficulties it was gradually abandoned after having served a great purpose in directing the attention of the world to the possibilities of the electric arc in lighting.

Inventors in America were not idle. By the close of 1878 Brush of Cleveland had brought out his series system of arc lights, including special dynamos, lamps, &c., and by the middle of 1879 had in operation machines, each capable of maintaining sixteen arc lamps on one wire. This was indeed a great achievement for that time. Weston of Newark had also in operation circuits of arc lamps, and the Thomson-Houston system had just started in commercial work with eight arc lamps in series from a single dynamo. Maxim and Fuller in New York were working arc lamps from their machines, and capital was being rapidly invested in new enterprises for electric lighting. Some of the great electric manufacturing concerns of to-day had their beginning at that time. Central lighting stations began to be established in cities, and the use of arc lights in street illumination and in stores grew rapidly. More perfect forms of light arc lamps were invented, better generating dynamos and regulating apparatus brought out. Factories for arc light carbon making were built. The first special electrical exhibition was held in Paris in 1881. In the early 80s also the business of arc lighting had become firmly established and soon the bulk of the work was done under two of the leading systems. These were afterward brought together under one control, thus securing in the apparatus manufactured a combination of the good features of both. Until about 1892 nearly all the arc lamps in use were worked under the series system, in which the lights were connected one after another on a circuit and traversed by the same current. This current has a standard value or is a constant current. Sometimes as many as a hundred lamps were on one wire. As the mains for the supply of incandescent lamps at constant pressure or potential were extended attention was more strongly turned to the possibility of working arc lights therefrom.

Within a few years of the close of the century this placing of arc lamps in branches from the same mains which supply incandescent lamps became common, and the inclosure of the arc in a partially air-tight globe, a procedure advocated by Staite in 1847, was revived by Howard, Marks and others for saving carbons and attention to the lamp. The inclosed arc lamp was also found to be especially adapted to use in branches of the incandescent lamp circuits, which had in cities become greatly extended. The increasing employment of alternating currents in the distribution of electric energy has led also to the use of alternating current arc lamps, and special current regulating apparatus is now being applied on a large scale to extended circuits of these lamps. It can be seen from these facts that the art is still rapidly progressing and the field ever widening. A little over twenty years ago practically no arc lamps were used. Now, at the close of the century, they are numbered by hundreds of thousands. The annual consumption of carbons in this country has reached two hundred millions.

Almost simultaneously with the beginning of the commercial work of arc lighting, Edison, in a successful effort to provide a small electric lamp for general distribution in place of gas, brought to public notice his carbon filament incandescent lamp.

A considerable amount of progress had previously been made by various workers in attempting to reduce the volume of light in each lamp and increase the number of lights for a given power expended. Forms of incandescent arc lamps or semi-incandescent lamps were tried on a considerable scale abroad, but none has survived. So, also, many attempts to produce a lamp giving light by pure incandescence of solid conductors proved for the most part abortive. Edison himself worked for nearly two years on a lamp based upon the old idea of incandescent platinum strips or wires, but without success. The announcement of this lamp caused a heavy drop in gas shares long before the problem was really solved by a masterly stroke in his carbon filament lamp. Curiously, the nearest approach to the carbon filament lamp had been made in 1845 by Starr, an American, who described in a British patent specification a lamp in which electric current passed through a thin strip of carbon kept it heated white when surrounded by a glass bulb in which a vacuum was maintained. Starr had exhibited his lamps to Faraday in England and was preparing to construct dynamos to furnish electric current for them in place of batteries, but sudden death put an end to his labors. The specification describing his lamp is perhaps the earliest description of an incandescent lamp of any promise, and the subsequently recorded ideas of inventors up to the work of Edison seem now almost in the nature of retrograde movements. None of them was successful commercially. Starr, who was only 25 years of age, is reported to have died of overwork and worry in his efforts to perfect his invention. His ideas were evidently far in advance of his time.

The Edison lamp differed from those which preceded it in the extremely small section of the carbon strip rendered hot by the current and in the perfection of the vacuum in which it was mounted. The filament was first made of carbonized paper and afterward of bamboo carbon. The modern incandescent lamp has for years past been provided with a filament made by a chemical process. The carbon formed is exceedingly homogeneous and of uniform electric resistance. Edison first exhibited his lamp in his laboratory at Menlo Park, New Jersey, in December, 1879, but before it could be properly utilized an enormous amount of work had had to be done. His task was not merely the improvement of an art already existing; it was the creation of a new art. Special dynamo machines had to be invented and constructed for working the lamps, switches were needed for connecting and disconnecting lamps and groups of lamps, meters for measuring the consumption of electric energy were wanted; safety fuses and cut-offs had to be provided; electroliers or fixtures to support the lamps were required, and, lastly, a complete system of underground mains with appurtenances was a requisite for city plants.

Even the steam engines for driving the dynamos had to be remodelled and improved for electric work, and ten years of electric lighting development did more toward the refinement and perfection of steam engines than fifty years preceding. Steadiness of lights meant the preservation of steady speed in the driving machinery. The Pearl street station in New York city was the first installation for the supply of current for incandescent lighting in a city district. The constant-pressure dynamos were gradually improved and enlarged. The details of all parts of the system were made more perfect, and in the hands of Edison and others the incandescent lamps, originally of high cost, were much cheapened and the quality of the production was greatly improved. Lamps originally cost $1 each. The best lamps that are made can be had at present for about one-fifth that price. Millions of incandescent lamps are annually manufactured. Great lighting stations furnish the current for the working of these lamps, some stations containing machinery aggregating many thousands of horse-power capacity. Not only do these stations furnish electric energy for the working of arc lamps and incandescent lamps, but in addition for innumerable motors ranging in size from the small desk fan of one-tenth horse power up to those of hundreds of horse power. The larger sizes replace steam or hydraulic power for elevators, and many are used in shops or factories for driving machinery such as printing presses, machinery tools and the like.

In spite of the fact that it was well known that a good dynamo when reversed could be made a source of power, few electric motors were in use until a considerable time after the establishment of the first lighting stations. Even in 1884 at the Philadelphia Electrical Exhibition only a few electric motors were shown. Not until 1886 or thereafter did the "motor load" of an electric station begin to be a factor in its business success. The motors supplied are an advantageous adjunct, inasmuch as they provide a day load, increasing the output of the station at a time when the lighting load is small and when the machinery in consequence would, without them, have to remain idle. The growth of the application of electric motors in the closing years of the century has been phenomenal, even leaving out of consideration their use in electric railways.

Twenty years ago an electric motor was a curiosity; fifty years ago crude examples run by batteries were only to be occasionally found in cabinets of scientific apparatus. Machinery Hall at the Centennial Exhibition of 1876 typified the mill of the past, never again to be reproduced, with its huge engines and lines of heavy shafting, and belts conveying power to the different tools or machines in operation. The modern mill or factory has its engines and dynamos located wherever convenient, its electric lines and numerous motors connected thereto and each of them either driving comparatively short lines of shafting or attached to drive single pieces of machinery. The wilderness of belts and pulleys which used to characterize a factory is gradually being cleared away and electric distribution of power substituted. Moreover, the lighting of the modern mill or factory is done from the same electric plant which distributes power.

The electric motor has already partly revolutionized the distribution of power for stationary machinery, but as applied to railways in place of animal power the revolution is complete. The period which has elapsed since the first introduction of electric railways is barely a dozen years. It is true that a few tentative experiments in electric traction were made some time in advance of 1888, notably by Siemens in Berlin in 1879 and 1880, by Stephen D. Field, by T. A. Edison at Menlo Park, by J. C. Henry, by Charles A. Van Depoele and others. If we look further back we find efforts such as that of Farmer in 1847 to propel railway cars by electric motors driven by current from batteries carried on the cars. These efforts were, of course, doomed to failure, for economical reasons. Electric energy from primary batteries was too costly and if it had been cheaper, the types of electric motor used yielded so small a return of power for the electric energy spent in driving them that commercial success was out of the question. These early efforts were, however, instructive and may now be regarded as highly suggestive of later work. Traction by the use of storage batteries carried on an electric car has been tried repeatedly, but appears not to be able to compete with systems of direct supply from electric lines. The plan survives, however, in the electric automobiles, many of which have been put into service within a year or two. The electric automobile is not well fitted for country touring, but is best adapted to cities where facilities for charging and caring for the batteries can be had. However, the electric carriages, of all automobile carriages the most easily controlled, most ready; it emits no smell of hot gases and is nearly noiseless.

About 1850 Hall, a well-known instrument maker of Boston, catalogued a small toy electric locomotive dragging a car upon rails which were insulated and connected with a stationary battery of two Grove cells. This arrangement was used as a piece of scientific apparatus and appears to be the first example of an electrically driven vehicle connected by rolling contacts to an immovable energy source. Other early experimenters, such as Siemens, Field and Daft subsequently to Hall used in actual railway work the supply by insulated tracks. This was supplanted later by overhead insulated wires or by the insulated third rail. Siemens & Halske of Berlin used a special form of overhead supply in 1881, and during the electrical exhibition in Paris in that year a street tramway line was run by them. Later Edison experimented with a third rail supply line at Menlo Park, and at Portrush, in Ireland, an actual railway was put into operation by Siemens & Halske using the third rail system. This was about 1883. The power of the Portrush railway was that of a water wheel driving the generating dynamo.

The modern overhead trolley or underrunning trolley, as it is called, seems to have been first invented by VanDepoele, and used by him in practical electric railway work about 1886 and thereafter. The universality of this invention for overhead supply marks the device as a really important advance in the art of electric traction. VanDepoele was also a pioneer in the use of an underground conduit, which he employed successfully in Toronto in 1884. The names of Edward M. Bentley and Walter H. Knight stand out prominently in connection with the first use of an underground conduit, tried under their plans in August, 1884, at Cleveland, on the tracks of the horse railway company.

We have barely outlined the history of the electric motor railway up to the beginning of a period of wonderful development resulting in the almost complete replacement by electric traction of horse traction or tramway lines, all within an interval of scarcely more than ten years.

The year 1888 may be said to mark the beginning of this work; in that year the Sprague Company, with Frank J. Sprague at its head, put into operation the electric line at Richmond, Va., using the underrunning trolley. Mr. Sprague had been associated with Edison in early traction work and was well known in connection with electric motor work in general. The Richmond line was the first large undertaking. It had about thirteen miles of track, numerous curves, and grades of from 3 to 10 per cent. The enterprise was one of great hardihood, and but for ample financial backing and determination to spare no effort or expenditure conducive to success, must certainly have failed. The motors were too small for the work, and there had not been found any proper substitute for the metal commutator brushes on the motors—a source of endless trouble and of an enormous expense for repairs. Nevertheless, the Richmond installation, kept in operation as it was in spite of all difficulties, served as an object lesson and had the effect of convincing Mr. Henry M. Whitney and the directors of the West End Street Railway of Boston of the feasibility of equipping the entire railway system of Boston electrically. Meanwhile the merging of the VanDepoele and Bentley-Knight interests into the Thomson-Houston Electric Light Company brought a new factor into the field; the Sprague interests being likewise merged with the Edison General Electric Company.

The West End Company, with 200 miles of track in and around Boston, began to equip its lines in 1888 with the Thomson-Houston plant. The success of this great undertaking left no doubt of the future of electric traction. The difficulties which had seriously threatened future success were gradually removed.

The electric railway progress was so great in the United States that about Jan. 1, 1891, there were more than 240 lines in operation. About 30,000 horses and mules were replaced by electric power in the single year of 1891. In 1892 the Thomson-Houston interests and those of the Edison General Company were merged in the General Electric Company, an event of unusual importance, as it brought together the two great competitors in electric traction at that date. Other electric manufacturers, chief among which was the Westinghouse Company, also entered the field and became prominent factors in railway extension. In a few years horse traction in the United States on tramway lines virtually disappeared. Many cable lines were converted to electric lines, and projects such as the Boston Subway began to be planned. Not the least of the advantages of electric traction is the higher speed attainable with safety. The comfort and cleanliness of the cars, lighted brilliantly at night and heated in winter by the same source of energy which is used to propel them, are important factors.

All these things, together with the great extension of the lines into suburban and country districts, and the interconnection of the lines of one district with those of another, cannot fail to have had a decidedly beneficial effect upon the life, habits and health of the people. While the United States and Canada have been and still are the theatre of the enormous electric advance in electric traction, as in other electric work, many electric car lines have in recent years been established in Great Britain and on the Continent of Europe. Countries like Japan, Australia, South Africa and South America have also in operation many electric trolley lines, and the work is rapidly extending. Most of this work, even in Europe, has been carried out either by importation of equipment from America, or by apparatus manufactured there, but following American practice closely. The bulk of the work has been done with the overhead wire and under-running trolley, but there are notable instances of the use of electric conductors in underground slotted conduits, chief of which are the great systems of street railway in New York city.

In Chicago the application of motor cars in trains upon the elevated railway followed directly upon the practical demonstration at the World's Fair of the capabilities of third-rail electric traction on the Intramural Elevated Railway, and the system is rapidly extending so as to include all elevated city roads. A few years will